

IDENTIFICATION OF THE SLOW WAVE OF SMALL BOWEL MYOELECTRICAL ACTIVITY BY SURFACE RECORDING

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Abstract. The bioelectrical signal (electroenterogram) is recorded at the abdominal surface of Beagle dogs with the aim of detecting the slow wave of small bowel myoelectrical activity. Electroenterogram comprises two signals: the slow wave, which is permanently present and establishes the maximum rate of intestinal contraction, and a series of rapid activity peaks generated at the plateau of the slow wave when the small bowel contracts. Two biosignals were recorded using bipolar electrodes: the internal myoelectric signal at a point of the jejunum serosa, and the bioelectric signal at the abdominal wall. The coherence function was used to evaluate the relation between the spectral contents of the two signals (internal and external). The results show high coherence function values for frequencies of under 2 Hz. A maximum was even detected for a frequency round 0.3 Hz, corresponding to the frequency of the slow wave (between 16 and 19 cycles/min.). Based on the coherence function, it is shown that the signal recorded at the abdominal surface is closely related to the slow wave component of the internal signal. The model employed therefore offers a noninvasive technique for recording small bowel myoelectrical activity.

Keywords - Surface recording, electroenterogram, small bowel, myoelectrical activity.

I. INTRODUCTION

For the gastroenterologist it is of great use to know the mechanical activity of the small bowel (intestinal motility), for such activity is directly associated to the process of digestion [1]. However, the difficulties in gaining access to this portion of the digestive tract have prevented the development of clinically contrasted techniques for recording such activity.

The most direct and widely employed approach to date has been the recording of pressure within the bowel, fundamentally based on the use of intraluminal probes, since this technique does not require surgery [2]. However, considerable controversy exists over this approach, due to its inherent physiological and technical problems [3, 4].

An alternative option is represented by the recording of myoelectrical activity (Fig. 1), which underlies intestinal smooth muscle contraction. In effect, the relation between intestinal mechanical and bioelectrical activity has been extensively demonstrated in the literature [1, 5].

The intestinal myoelectrical signal (electroenterogram) has two components (Fig. 1): a slow wave (SW) which is

permanently present and regulates contraction rates, and the so-called spike bursts (SB), which are only generated when the smooth muscle cells contract. The SB appear on the plateau of the SW (Fig. 1), and their quantification can be used as a motility index [1, 5].

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However, recording of the electroenterogram requires surgery - this being a clear inconvenience for clinical application of the technique. The solution to this problem would be to record the myoelectrical signal from the external abdominal surface. The aim of the present study is to identify the SW of the electroenterogram through external recording.

II. MATERIAL AND METHODS

Three Beagle dogs were subjected to surgery to implant a series of bipolar electrodes along the length of the small bowel [5]. For the purpose of the present study only the results corresponding to the electrode positioned at jejunal level will be presented (located at a distance of 70 cm from the duodeno-jejunal angle). The intestinal ring at this measurement point was affixed to the internal surface of the abdominal wall, close to the navel, to serve as reference for the surface recording.

The external signal was recorded by two Ag-AgCl monopolar electrodes measuring 12 mm in diameter each one, with an inter-electrode distance of 2 cm, and positioned on the abdominal skin in the zone where the internal reference electrode was affixed.

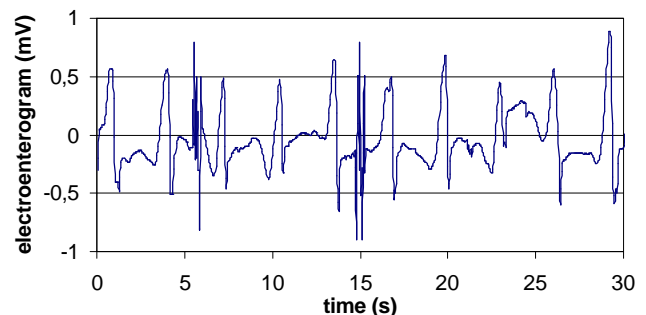


Fig. 1. Small bowel myoelectrical activity (electroenterogram) recorded at duodenal level. There are approximately 9 slow waves (SW) in these 30 sec.

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Eight recording sessions were carried out, involving the acquisition of at least one interdigestive migrating myoelectric complex (IMMC). Accordingly, the animals were previously fasted for more than 12 hours. Each session implied the recording of more than 150 min. of combined signals (external and internal).

Of the total minutes recorded, analysis was limited to the period without mechanical contraction, i.e., the internally recorded electroenterogram consisted only of SW. The minutes during which external signal artifacts were observed were likewise excluded from the analysis. Fig. 2 shows a one-minute acquisition of both signals.

The signals were amplified with a bandwidth of [0.05 Hz, 35 Hz]. The sampling frequency was 100 Hz. Following acquisition, both signals were preprocessed with a low-pass filter of 8 Hz and decimated by 4; i.e., the sampling frequency was 25 Hz.

For each session, the coherence function between both signals was estimated [6], calculated as the average of the coherence functions of each minute analyzed in this session:

$$\tilde{a} = \frac{1}{M} \sum_{i=1}^M \tilde{a}_i \quad (1)$$

where M are the minutes analyzed, and γ_i is the coherence function estimated for the minute i, which is:

$$\tilde{a}_i^2 = \frac{|S_{xy}|^2}{S_{xx} \cdot S_{yy}} \quad (2)$$

where S_{xy} is the estimated cross-spectral density function and S_{xx} S_{yy} are the estimated autospectral density functions. Both functions (cross-spectral and autospectral) were estimated taking 5 rectangular time windows (of 20 sec. each) with 50% overlapping.

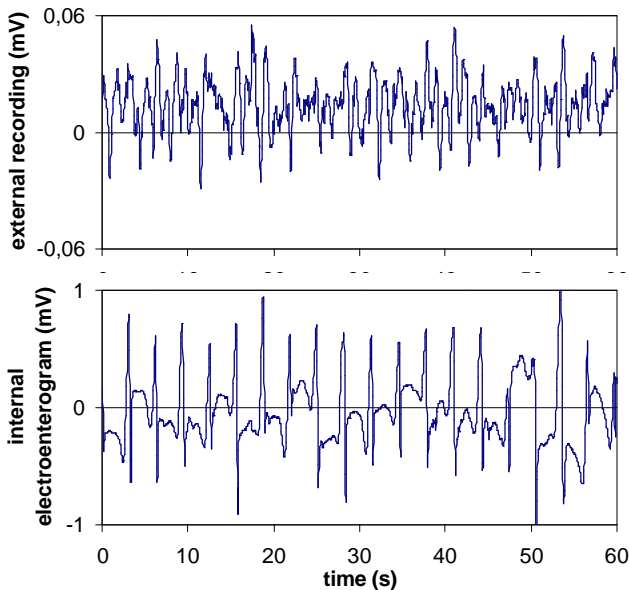


Figure 2. One-minute of external (upper trace) and internal (lower trace) small bowel myoelectrical activity recording.

Fig. 3 shows the estimation of the coherence function (γ_i) for the signals presented in Fig. 2. The corresponding frequency resolution is $\Delta f=0.05$ Hz. On the other hand, the estimation provided in Fig. 3 contains important error, since only three independent windows were taken for calculation [6]. Consequently, the results presented for discussion are the coherence functions averaged for all the minutes corresponding to a recording session (1).

III. RESULTS

Fig. 4 shows the coherence function calculated for one of the recording sessions (session G). Calculation involved 70 min.; i.e., the number of independent windows (each of 20 sec.) was 210.

The mean coherence function value presented in Fig. 4 is $\gamma_{med}=0.45$. Based on this value, the corresponding 95% confidence interval can be calculated [6], yielding $\gamma \in [0.36, 0.52]$. The confidence interval improves with increasing coherence for a given frequency [6].

The minimum number of minutes used in a recording session for estimating the coherence function was 36 (session F), which implies 108 independent windows. In this session the mean value of the coherence function was $\gamma_{med}=0.46$. Based on this value the corresponding 95% confidence interval could be calculated [6], yielding $\gamma \in [0.34, 0.56]$.

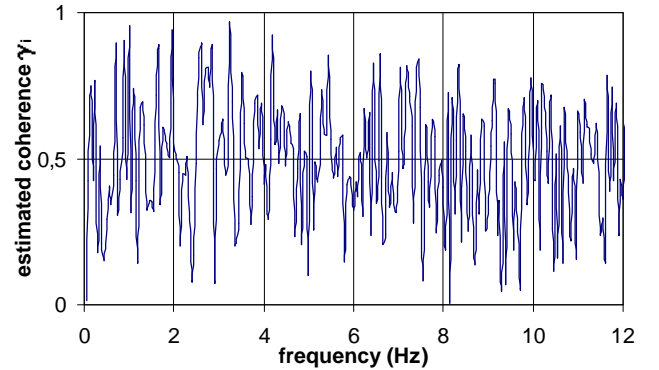


Figure 3. Coherence function estimated (γ_i) between external and internal myoelectrical activities shown in Figure 2.

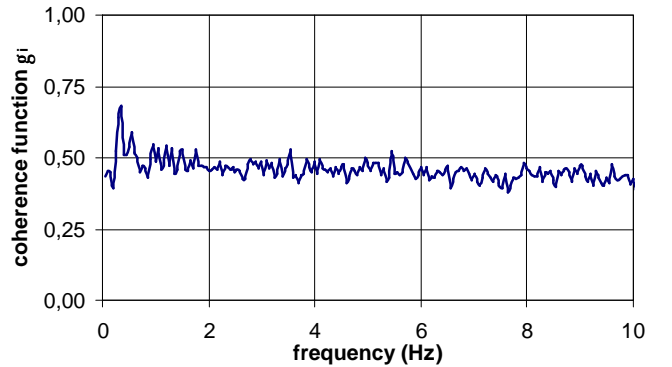


Figure 4. Coherence function estimated (γ) with 210 independent windows (20 sec.) between the external and internal myoelectrical activities.

Fig. 4 shows coherence to be under 0.5 in all cases for frequencies above 2 Hz. However, for lower frequencies the coherence values increase, a maximum value of 0.68 being observed for a frequency of 0.3 Hz.

Table I presents the maximum values of the coherence function for each recording session, and the corresponding standard deviations. The frequencies at which these maximum values are obtained are also shown. The large magnitude of these maximum values indicate an important correlation in the spectral domain between the signals recorded at the internal measurement point and those recorded at the abdominal surface.

It is important to point out that these maximum values always correspond to frequencies of under 1 Hz. Although it may seem that no exact frequency is associated with maximum correlation between the internal and external signals, a relative maximum was always obtained between 0.30 and 0.35 Hz.

In order to draw conclusions, and in view of the similarity obtained in the coherence functions of each session, Fig. 5 presents a pondered average of the 8 coherence functions. The maximum value of the function (0.65) corresponds to a frequency of 0.3 Hz.

TABLE I
MAXIMUM VALUES OF COHERENCE FUNCTION AND FREQUENCY

Session	M (minutes)	Maximum value \pm sd	Frequency (Hz)
A	70	0.84 \pm 0.04	0.65
B	81	0.74 \pm 0.06	0.30
C	50	0.87 \pm 0.04	0.65
D	49	0.58 \pm 0.08	0.30
E	88	0.53 \pm 0.06	0.70
F	36	0.60 \pm 0.09	0.30
G	70	0.68 \pm 0.06	0.30
H	55	0.71 \pm 0.07	0.35

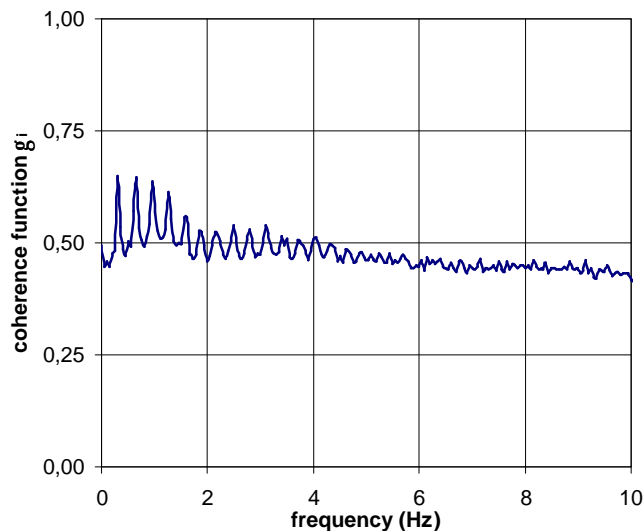


Figure 5. Coherence function averaged from 8 recording sessions.

IV. DISCUSSION

The myoelectrical signal recorded at small bowel serosal level was used as reference to evaluate the possibility of recording the same signal from the external abdominal surface. The results obtained (Table I) indicate a high correlation in the spectral domain between both signals (internal and external), and support the opinion of other authors that small bowel myoelectrical activity can be recorded from the surface of the abdomen [7, 8].

A peak was observed for all the coherence functions estimated at a frequency of 0.3 Hz. Indeed, even on averaging all the coherence functions (Fig. 5), the maximum value corresponded to this same frequency. The latter in turn corresponded to the jejunal slow wave, which in dogs is located in the range of 15 to 18 cycles per minute.

In any case, the energy of the slow wave of the internal recording was located below 2 Hz [5], and in this frequency range the coherence function was seen to yield greater values than at frequencies above 2 Hz. This means that the correlation between the internal and external signals is due to the energy component of the intestinal slow wave. This observation coincides with other studies involving the detection of myoelectrical activity, which have focused only on the slow wave of the electroenterogram [7, 8].

The spectral resolution in the present study was 0.05 Hz, i.e., sufficient to discriminate whether maximum correlation is due to cycling of the slow wave or to breathing of the animal - which exceeds 20 cycles/min [7]. The external signal could possibly record breathing interference, though the frequency of the latter is different to that of the SW of the internal signal - i.e., the correlation between both would not be so appreciable. This coincides with the findings of other authors [7, 9], though some adaptive filter is effectively needed to avoid respiratory interference [9].

In earlier studies we have observed a relation between both signals when quantifying spike-burst (SB) energy [10]. This study was very useful for defining an intestinal motility index, since only SB imply contraction of the intestinal ring. However, in doing so the energy contributed by the SW is completely eliminated. Otherwise, present study considers the influence of the SW in surface recording, which can be useful for diagnosing intestinal dysfunction without surgical intervention.

V. CONCLUSION

Following analysis of the spectral domain, the bioelectrical signal recorded at the abdominal surface is seen to be closely correlated to the myoelectrical signal of the small bowel.

The frequencies for which the closest relation was observed between the external and internal signals corresponded to those of the slow wave of the electroenterogram (internal recording) - thus suggesting that the slow wave is largely reflected in the abdominal surface recordings.

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